Induction of Interfacial Gradients to Generate Drop Motion and Internal Flows

喜多, 由拓

出版情報：Kyushu University, 2018, 博士（工学），課程博士
バージョン：
権利関係：

（様式２）

氏　　名　：喜多　由拓

論 文 名　：Induction of Interfacial Gradients to Generate Drop Motion and Internal Flows
（濡れ性および界面温度勾配による液滴移動および内部対流発生に関する研究）

区　　分　：甲

論　文　内　容　の　要　旨

This thesis is devoted to experimentally elucidating the dynamics of liquid drops on gradients at the interfaces *i.e.* temperature and wettability gradients. A drop driven away from the equilibrium state will be “active” and will act in order to attain the energetically favourable state, inducing flows or drop motion. Actions that drops make in such situation are not merely of fundamental scientific interest but also exploring ways to activate or control a system containing drops has progressively become of importance in industrial and biomedical applications. The present study deals with drops of pure water, which is ubiquitous but unique, and investigates their thermocapillary-driven instabilities induced by localised heating and mobility on wettability gradients imposed via superhydrophobic microstructure patterning.

The First problem addressed in the thesis is the existence of thermocapillary “Marangoni” flows in pure water which has been a long-standing controversial issue due to an ambiguity between theoretical predictions and little experimental evidence. The thesis reports the very first observation/visualisation of Marangoni-driven counter-rotating vortices in a pure water drop using infrared thermography coupled with optical particle imaging (Figure 1). The flows are induced by imposing a thermal gradient along the drop surface by locally heating the substrate directly underneath the centre with a laser. The origin of the flows is identified by comparing the dimensionless Marangoni and Rayleigh numbers, which shows the dominance of thermocapillary convection over buoyancy. This is further corroborated by a second set of experiments with an inverted system where the same flow patterns are observed regardless of the gravity orientation.

Secondly, as a systematic analysis, the effect of heating power and location on Marangoni flows as well as evaporation of water drops is studied. Heating location is found to have a major impact on the flow patterns as recirculating vortices travel azimuthally within the drop when heating the centre whereas the flow direction remains fixed during edge heating. Further analysis of thermographic data allows to calculate the flow velocity which appears to increase for higher heating power as well as for the edge-heating case. Moreover, evaporation kinetics such as the rate of vaporisation and triple-line motion is found to be subject to the effect of local heating.

In addition to internal flows induced by thermal gradients, the last part of the thesis focuses on mobility of millimetre-sized water drops propelled by wettability contrasts/gradients. To this end, micropillar fabrication on hydrophobic surfaces is used in the present work to engineer wettability contrasts by virtue of their wettability controllability and resultant superhydrophobic characteristic. A millimetre-sized water drop, placed at the boundary between two surfaces with different pillar densities, spontaneously moves toward the surface with more densely populated asperities, which is relatively more hydrophilic (Figure 2).

Drop motion is found to accelerate proportionally with the difference in pillar densities on each surface, provided that the rear-side surface has sufficiently small pinning effect or contact angle hysteresis. Furthermore, an analysis of surface free energy is implemented to rationalise the drop motion. Coupling the energy analysis with the experimental observations reveals that motion is initiated by the excess surface energy due to drop deformation and is directed in favour of energy minimisation. Lastly, a thermodynamic theory to predict the direction of the drop which at the same time suggests the criterion for the motion to ensue is proposed.

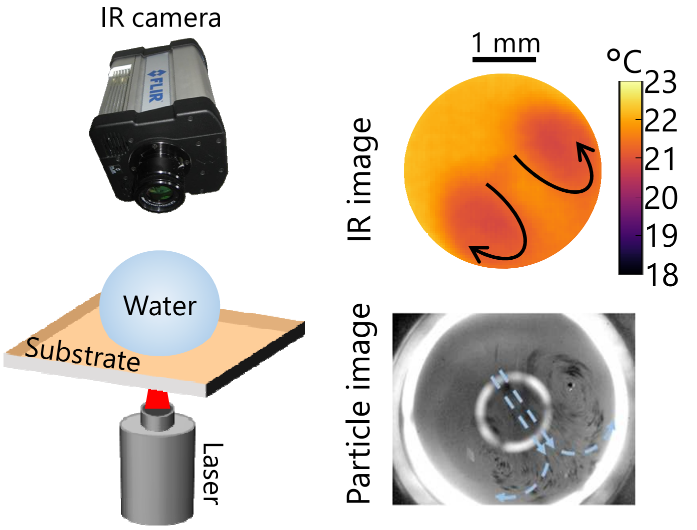

Figure 1 Infrared and particle imaging visualisation of thermocapillary flows in pure water drops induced by localised heating.

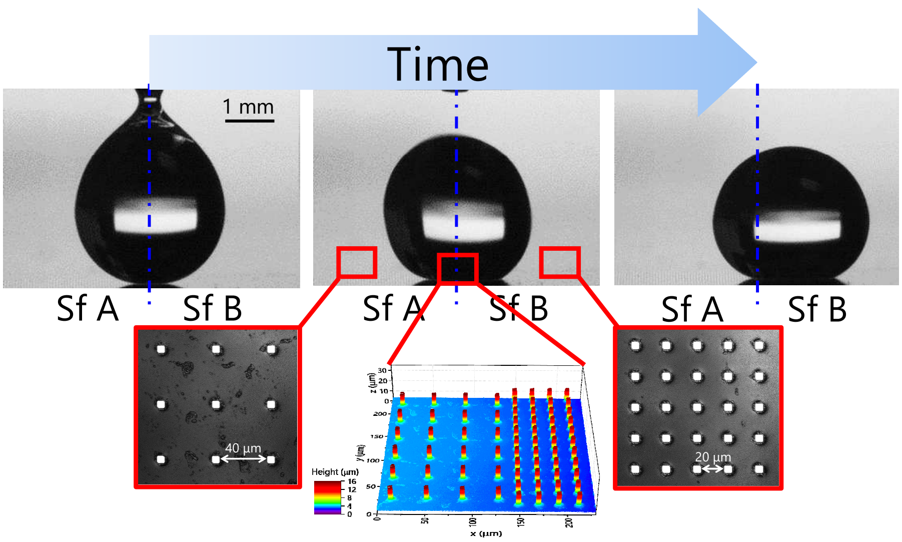

Figure 2 Drop motion on the boundary between two surfaces with different pillar patterns.